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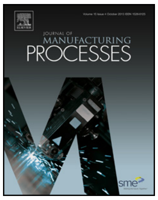

Technical Paper

Mechanical behaviour of ABS: An experimental study using FDM and injection moulding techniques

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ABSTRACT

Fused deposition modelling (FDM) in contrast to injection moulding was studied to investigate the effect of processing technique on the mechanical behaviour of virgin ABS. FDM parameters were further altered in terms of varying raster angle and gap to further explore the potential of this technique. Results show that an adequate selection of FDM parameters is able to reach mechanical properties comparable to those of injection moulded parts in both static and dynamic loading modes. Here, a negative raster gap proved to be most significant in enhancing mechanical behaviour. A raster angle layup of −45°/+45° proves to offer maximum tensile and impact strength, whereas highest flexural strength was recorded for a 0/90° scaffolding system. In contrast, a positive gap drastically reduces the performance. Dimensional analysis further show no significant alterations of dimensions are to be expected with varying raster angle and gap.

1. Introduction

3D Printing (3DP) is a technology used to directly convert 3D Computer-Aided Design (CAD) data into physical prototype. Most 3D printing techniques are based on slicing a CAD model into a number of 2D layers and building them layer by layer to form the prototype.

One of many available 3DP techniques is Fused Deposition Modelling (FDM) [1,2]. In this process a filament of material is melted in a heated nozzle and deposited on a build platform. By using a 3-axis motion system, this nozzle is moved in the XY plane printing a layer of the prototype. When this layer is finished, the build platform is moved down one step (known as the slice thickness) in the Z direction and the cycle is repeated for the next layer until the complete model is built-up [3].

FDM technology is primarily used for rapid prototyping polymer parts [3,4]. The choice of material depends on the type of application and desired properties. Nowadays, commonly applied materials include Polylactic Acid (PLA) as a stiff and environmentally-friendly material, Nylon for soft applications (e.g. bracelets), high density polyethylene (HDPE) for the production of food-compatible parts and Acrylonitrile Butadiene Styrene (ABS) as a general solution for tough parts with acceptable strength.

In recent years, FDM technology has gained a public interest for its ease of use as well as the simplicity of the machinery itself. Today, many FDM machines are designed and constructed by hobbyists as a Do-It-Yourself (DIY) machine for personal use [5]. These even assume that in the coming years, many of our daily-use plastic products, especially spare parts that are produced by Injection Moulding (IM) will be replaced by CAD models that would be home printed for cost reductions and personalization. A problem, however, remains the expected loss in mechanical properties in contrast to the monofilament or the injected material [2,6].

Whereas layer thickness, part orientation and raster width were proven to have little influence on mechanical properties [2,7], other printing parameters such as raster angle and air gap between two successive rasters were observed to significantly affect the performance of 3DP parts [2,7–9]. Sood et al. [2] observed that tensile strength is enhanced by increasing the raster angle. In contrast, Vega et al. [8] reported a maximum tensile strength at a raster orientation of 0° to the tensile load. This angle of zero additionally proved to be most suited for maximum flexural strength [2,8]. Further investigations conducted by Sood et al. [7] show failure of 3D parts due to buckling or debonding of adjacent rasters upon the application of compressive loads.

A positive air gap was proposed to allow material flow towards adjacent layers thus contributing to the enhancement of mechanical properties [2]. In contrast, Ahn et al. [9] describe that a negative air gap of 0.003″ (0.08 mm) between rasters increases part density thus enhancing tensile behaviour. A more negative air gap leading

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Table 1
Overview of previous work in FDM technology.

Reference	Machine	Raster angle	Other printing parameters	Mechanical properties	Form accuracy
[2,7]	Stratasys	0, 30, 45, 60	Raster gap, raster width, layer thickness, layer orientation	Tension, compression bending, impact	Dimensions
[8]	Stratasys	0, 45, 90, 45/−45, 45/0	Layer orientation	Tension, bending, impact	–
[9,15]	Stratasys	0, 90, 0/−90, 45/−45	Raster gap, raster width, printing temperature	Tension, compression	–
[6,16]	Stratasys	0, 90	Raster gap, raster width, printing temperature	Tension, torsion	–
[10]	Stratasys	–	No. of contours, layer orientation	Tension	–
[17]	Stratasys	0/-90, 30/-60, 45/-45		Bending	–
[18]	Stratasys	–	Raster width, no. of contours, envelope temperature, printing temperature	–	Voids
[19]	Stratasys	–	Raster width, layer thickness, deposition speed	–	Roughness
[20]	Stratasys	–	Raster width, layer thickness	–	Dimensions, roughness
[21,22]	Stratasys	0, 30, 60, 90, 0/−90, 15/−75, 30/−60, 45/−45	–	Tension	–
Study	DIY	0/−90, 15/−75, 30/−60, 45/−45	Raster gap	Tension, bending, impact	–

to raster overlap would, however, lead to dimensional inaccuracy. Similarly, Croccolo et al. [10] suggest improved strength through increased number of contours.

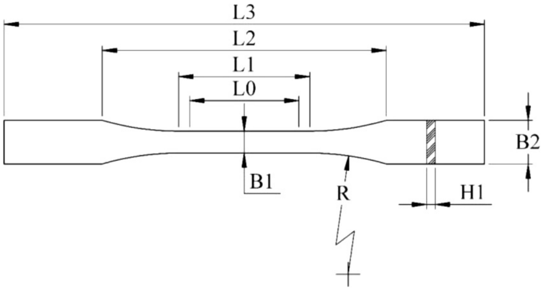
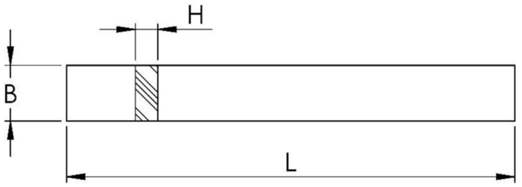
Table 1 gives an overview of the parameters and mechanical properties of FDM products intensively investigated in literature. However, literature lacks an in-depth study of the criss-cross (+/−) meshing system, where the raster angle in each layer is orthogonal to the preceding layer. This meshing system is the main system used by open source slicing software used in DIY 3D printer projects. Studies are based, however, on commercially available FDM equipment, relying on a single raster angle that is constant for all the layers as a meshing system. In this context, based on the use of DIY machines the authors propose a comparison of mechanical properties for the commonly applied Acrylonitrile Butadiene Styrene material processed by injection moulding and fused deposition modelling in order to highlight the difference in mechanical properties encountered by the different processing techniques. Further, the effect of FDM printing parameters on the performance of printed parts is investigated, targeting the selection of appropriate parameters that enable the fabrication of parts of comparable behaviour to injection moulding.

2. Experimental work

2.1. Materials

Virgin ABS pellets supplied by Grand Pacific Petrochemical Corp (D-150) [14] were used to extrude ABS filament for subsequent FDM and injection moulding processing. Pellets were first dried at 80 °C for 24 h prior to extrusion into 1.7 ± 0.05 mm filaments using

Table 2
Dimensions of tensile, flexural, and impact specimens.

	Parameter	Injected specimen	3D printed specimen
Tensile specimens			
	Gauge length L0 [mm]	50 ± 0.5	50 ± 0.5
	Length of parallel section L1 [mm]	60 ± 0.5	60 ± 0.5
	Distance between shoulders L2 [mm]	107.5	120
	Total length L3 [mm]	195	220
	Width of the parallel section B1 [mm]	10 ± 0.2	10 ± 0.2
	Width at ends B2 [mm]	20 ± 0.2	20 ± 0.2
	Thickness H1 [mm]	4 ± 0.2	4 ± 0.2
	Fillet Radius R [mm]	40	125
Bending and impact specimens			
	Overall length L [mm]	80 mm ± 0.2	80 mm ± 0.2
	Width B [mm]	10 mm ± 0.2	10 mm ± 0.2
	Thickness H [mm]	4 mm ± 0.2	4 mm ± 0.2